Appendix A
<u>SLS Mission Requirements and Reference Vehicle Technical Data</u>

1.0 <u>Introduction</u>

NASA is examining potential Advanced Booster concepts, as future block upgrades, to enable the Space Launch System (SLS) heavy lift launch vehicle to meet its ultimate program and mission goals. There are no current booster design solutions that provide the propulsive performance necessary to accomplish the larger payload Design Reference Missions (DRMs) being contemplated for future capabilities.

The SLS Advanced Booster Engineering Demonstration and/or Risk Reduction (ABEDRR) will meet the program goal of improving affordability, performance, and reliability by funding selected EDRR activities in areas critical to the development of Advanced Booster concepts presented by the selected Offerors.

The SLS launch vehicle performance requirements and configuration are currently under development, although the ultimate goal of 130 metric tons (286,601 lbm) mass to Low Earth Orbit (LEO) is remaining firm. As an illustration of the size class of launch vehicle being considered, Figure 1 shows two prospective Block 2 configurations being studied to fulfill the heavy lift goals. (Figure 1 shows the configurations with a solid Advanced Booster. The SLS 22001 and 24001, cargo and crewed, vehicle series utilize a liquid Advanced Booster.)

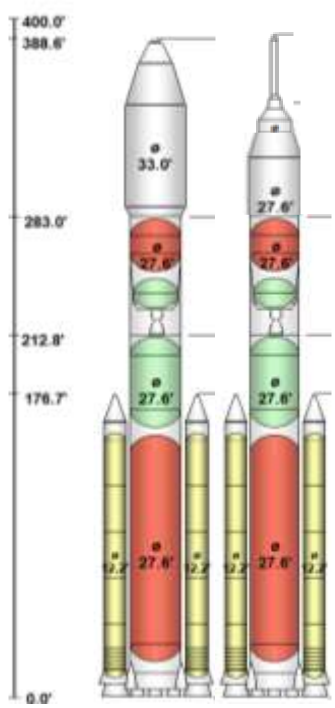

Figure 1 – NASA Notional SLS 21001 & 23001 (Block 2) Cargo & Crewed Configurations
(Both Shown with a Solid Advanced Booster)

The technical information is provided in this Appendix A and Appendix B, Sheets 1.1 through 1.6 to perform a first order sizing and trajectory analysis of a reference vehicle with an Advanced Booster concept provided by the Offeror, which will allow the Offeror to propose its respective risk mitigation demonstrations based on its reference vehicle maturity and risk assessment. Appendix B is available on the Technical Library on Knowledge Now (https://nsckn.nasa.gov/). Note that the Offeror must be approved for secure access to the Technical Library. NASA is also providing a pertinent subset of vehicle level requirements and interface constraints in Section 4.0 of this Appendix that significantly affect sizing of the launch vehicle. The Offeror shall use the data provided to develop its Advanced Booster concept. It is expected that the Offeror will "run" its respective Advanced Booster concept in the proposed reference vehicle and compare its trajectory results to the NASA provided results to ensure that the Offeror has properly modeled the performance and characteristics of the core vehicle. NASA will evaluate the Offeror's vehicle concept .

2.0 Reference Launch Vehicle Description

This section describes basic data for the reference launch vehicle that shall be used by the Offeror. This section provides information for either a Solid Rocket Booster (SRB) or Liquid Rocket Booster (LRB) for the Advanced Booster, Core Stage (CS), Upper Stage (US), and Non-propulsive Payload Element (NPE) to be used by the Offeror to develop its Advanced Booster concept.

2.1 Advanced Booster Stage Description

The current booster stage for the initial SLS configuration is based on the Space Shuttle configuration and consists of a pair of boosters. With the initial assumption to minimize costs to modify existing systems, the Advanced Booster will also consist of a pair of boosters, one left-hand and one right-hand booster, each assembled in parallel and attached to the CS with mating hardware utilizing forward and aft mechanical attach points on each booster. The Advanced Booster will also interface with the Mobile Launcher (ML) at the eight existing mechanical hard points and will carry the gross weight of the vehicle to the ML.

Both Advanced Boosters consisting of a liquid propellant or solid propellant propulsion system and systems for structural support, thrust vector control (TVC), power, avionics, instrumentation, mating/attachment and separation, and range safety. The mating hardware attaches the Advanced Booster to the ML and to the CS. The mating hardware has the capability to release the Booster from the ML at liftoff and to separate the Booster from the core vehicle at the appropriate time during ascent.

Appendix B, Sheet 1.2, lists the mass and propulsion properties for the NASA reference booster elements. Coverage includes information for a solid and a liquid booster system. For the solid booster, an average thrust is given. However, for a higher fidelity performance analysis, the complete thrust trace (vacuum thrust and mass flow rate) shown in Appendix B, Sheet 1.3, should be used.

2.2 Core Stage Description

NASA has selected key hardware elements of the initial SLS vehicle architecture and is actively developing these elements including the CS. The CS is a cryogenic liquid oxygen / liquid hydrogen (LO2/LH2) propulsive stage. The CS is designed for upper thrust takeout at the inter-stage location between the hydrogen and oxygen tanks, similar to the Shuttle architecture. The Advanced Boosters will structurally support the CS and other stages during assembly, roll out, flight preparation, and through lift-off and ascent to booster separation. The CS provides continuous impulse from engine ignition (just prior to liftoff) through CS engine shutdown and is designed for use in either 1.5 stage or 2.5 stage configurations. For 1.5 stage use, the CS provides final stage performance to orbit injection with sufficient flight performance propellant reserve set aside. For 2.5 stage use, the CS provides intermediate stage performance using all available impulsive propellant (no FPR set aside).

The CS will utilize a new RS-25E engine as the Core Stage Main Engine (CSME). Five RS-25E engines will provide propulsion for the CS. The RS-25E will be derived from the RS-25D or Space Shuttle Main Engine (SSME), and will be re-designed for lower cost. Estimated performance for the RS-25E is provided in Appendix B, Sheet 1.2.

2.3 Upper Stage Description

The US is a cryogenic LO2/LH2 propulsive stage.
The US will utilize two J-2X engines as the propulsion for the US. The sizing and performance data for the J-2X are provided in Appendix B, Sheet 1.2, for either a LRB or SRB Advanced Booster concept.

2.4 Non-propulsive Payload Element Description

Appendix B, Sheet 1.2, also describes the mass characteristics of an inert NPE. For the purposes of sizing a reference vehicle, the hardware elements above the US, including a 33 ft diameter shrouded payload carrier, are included in the NPE. The NPE is intended to generally represent and encompass the mass and dimensions of potential future cargo.

3.0 Reference Mission Information

This section briefly describes a reference mission for a heavy-lift reference vehicle to deliver 130 metric tons mass to LEO. The NASA-provided data is to be used by the Offeror to develop its Advanced Booster concept and verify with its reference launch vehicle configuration in a flight simulation analysis. This will confirm for the Offeror that it has implemented its Advanced Booster concept appropriately and that valid results will be obtained when simulating the flight performance of its reference vehicle. In turn, this will also provide substantiation for the Offeror's submitted high risk areas and/or proposed risk mitigation demonstrations.

Technical information for two scenarios are provided in Appendix B, Sheet 1.2, one representing a LRB and one representing a SRB solution. Assumptions for the CS, US, and NPE are the same for both scenarios. However, several key assumptions related to booster configuration will differ and are described in the following paragraphs.

For the LRB, hold-down release occurs when the calculated thrust-to-weight (T/W) of the reference vehicle reaches 1.2. This condition should be met when all engines have completed their startup transients and are operating at their respective design liftoff thrust levels. Since engine transients are not modeled in NASA's reference missions, the LRB engine thrust is adjusted to produce this condition at T=0. For example, the thrust level for the liquid system shown in Appendix B, Sheet 1.2, reflects this adjustment. Note that this value is based on NASA's analysis and will be dependent on vehicle gross weight at liftoff (GLOW). Alternative liquid concepts should account for this T/W limit. For the SRB, hold-down release occurs when the calculated vehicle T/W reaches 1.0.

Startup and shutdown propellant usage is also accounted for in the NASA model. However, this ground rule is only applied to the CS and US elements. The LRB is assumed to consume all usable propellant. For the SRB, an initial propellant weight is assumed. Near burn out, if any propellant remains after a separation trigger of 40,000 lbf net thrust (per booster) is reached, that propellant is assumed to be part of the booster jettison weight.

For modeling of US propellant inventory, additional propellant management is required. Calculation of flight performance reserve (FPR) for the US will vary dependent upon the total Ideal Delta-V for the given scenario (i.e. liquid versus solid booster). This will limit the amount of nominal impulse propellant available in the US. As a ground rule, 1.6% of the total Ideal Delta-Velocity is to be set aside as FPR.

Large database information (such as aerodynamic data) for the vehicle is not contained in this technical information but is available in ancillary documentation provided with the SLS NRA for ABEDRR Technical Library.

3.1 Launch Site Location

All NASA design reference trajectories and performance analyses for the SLS heavy lift launch vehicle analyses assume launch from the Eastern Test Range (ETR) using the parameters as noted in Appendix B, Sheet 1.1. The specific references noted are used to determine the location of the vehicle Redundant Inertial Navigation Unit (RINU) relative to the geodetic model of the Earth as defined in National Imagery and Mapping (NIMA) Technical Report TR8350.2. Requests for further information concerning the values may be submitted to the Contracting Officer.

3.2 Mission Simulation Timeline

The mission sequence provided in Appendix B, Sheet 1.4, describes the mission profile for a notional 130 metric ton class cargo mission. The sequence steps apply equally to either a liquid or solid Advanced Booster concept unless specific comments are provided.

3.3 Ascent Environments and Vehicle Aerodynamics

Earth gravitational and atmospheric models used for development of SLS reference trajectories are provided in Appendix B, Sheet 1.1. The vehicle aerodynamic body reference and model data are also included in the SLS NRA for ABEDRR Technical Library. The Gravity Recovery and Climate Experiment (GRACE) gravity model is available on the Internet. The aerodynamic force and moment database is provided as an ancillary document to the NRA and will be provided in the associated NRA technical library. This database is preliminary and may be used by the Offeror (if needed) in its simulations in lieu of any data available. The Global Reference Atmospheric Model (GRAM) model is managed by NASA-MSFC Guidance, Navigation, and Control (GN&C) and access is ITAR restricted. Requests for the GRAM-2007 and GRAM-2010 model data may be made through the NRA Contracting Officer.

3.4 State at Mass Injection

Appendix B, Sheet 1.4, identifies the ascent targets currently in use for development of SLS reference trajectories and performance analyses. These targets have been determined to provide for safe disposal of the CS for ascent to LEO and Lunar pre-Trans-Lunar Injection parking orbit. Note that the payload is assumed responsible for any maneuvers needed to produce sustainable orbit (e.g. perigee raise to minimum safe height). Also note that these targets are not exclusive. Ascent to other targets is permissible; however, performance to other targets has not been assessed, nor injection altitudes appropriate for Core disposal determined. Payload and path performance for this NRA will be evaluated against the -47x130 nmi target orbit. Note that all altitude targets are referenced to a 6,378.1369 km (3443.918 nmi) radius sphere.

4.0 Technical Requirements for the Reference Vehicle

A minimum set of key requirements and mechanical interfaces were selected that are first order sizing drivers for a reference launch vehicle, with the Offeror’s proposed Advanced Booster.

4.1 Mass to Orbit

As provided in the reference vehicle and mission description (Appendix B, Sheets 1.1 through 1.6), the mass to orbit is a fundamental requirement to attain. The requirement is 130 metric tons to LEO delivered to the provided end-state conditions. The Offeror is allowed to discuss its mass-to-orbit performance margin in a qualitative manner.

4.2 Booster to Core Stage Mechanical Interface

The SLS CS to Booster mechanical interfaces are based on the Block 1 configuration, which accommodates two five-segment Reusable Solid Rocket Motors (RSRMV) boosters, attached 180 degrees apart on either side of the CS. Figure 2 illustrates the nominal elevations and mechanical interfaces for the forward and aft attachment of the CS to Booster and the Booster to ML in the “hard down” configuration for stacking and launch.

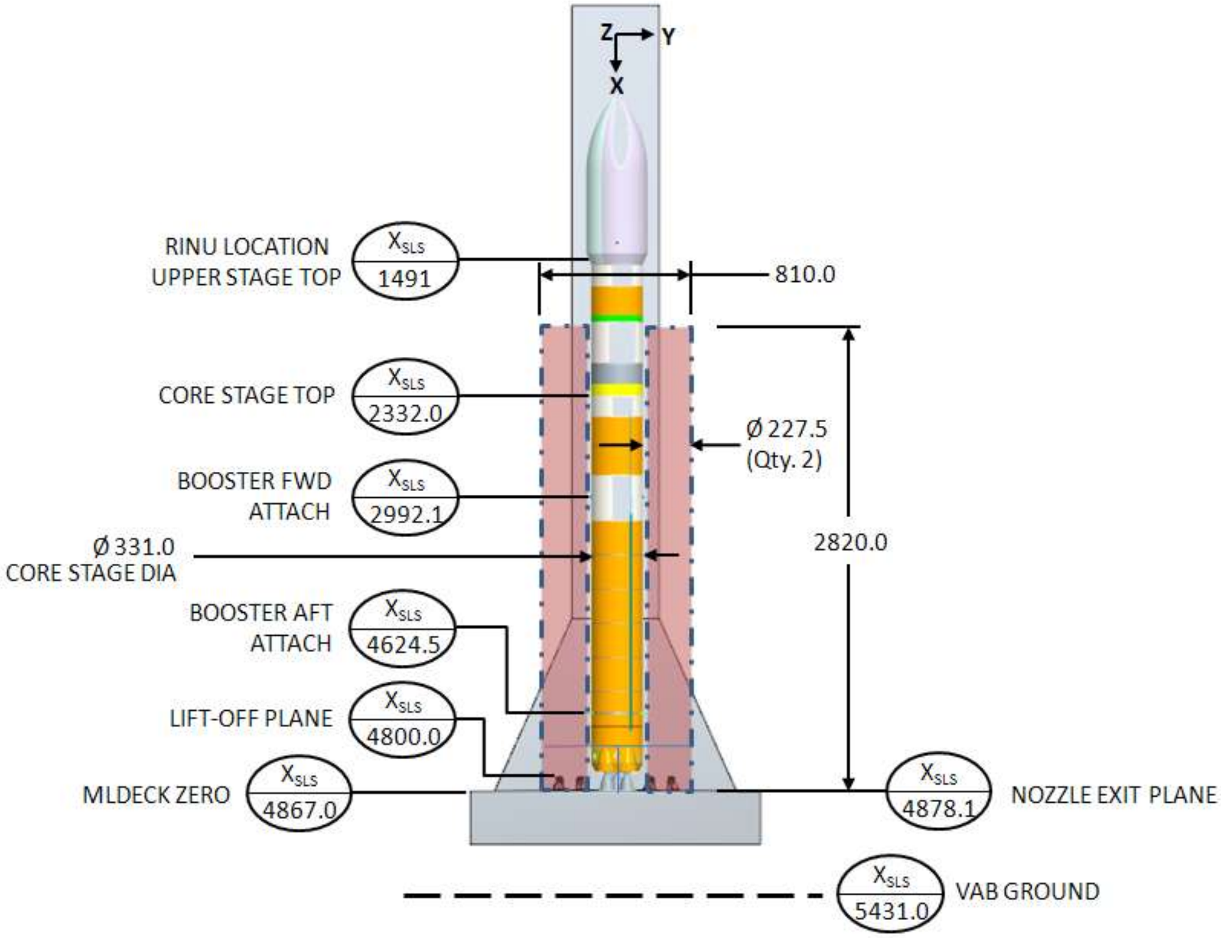

Figure 2 – NASA Elevation Drawing - Mechanical Interfaces & Sizing Constraints

4.3 Booster to Ground Systems Mechanical Interface

The SLS draft booster-to-ground interface is based on the initial Block 1 (SLS 10000) configuration, and includes two RSRMV boosters, attached 180 degrees apart on either side of the CS. Figures 3 and 4 illustrate the general layout of the vehicle on the ML deck, the dimension of the plume hole, and the in-plane location of the eight lift-off posts. A description of any necessary configuration modifications to the ML plume holes and lift-off posts with associated cost estimates to accommodate the Offeror's Advanced Boosters shall be included. The Offeror does not have to account for further infrastructure modifications.

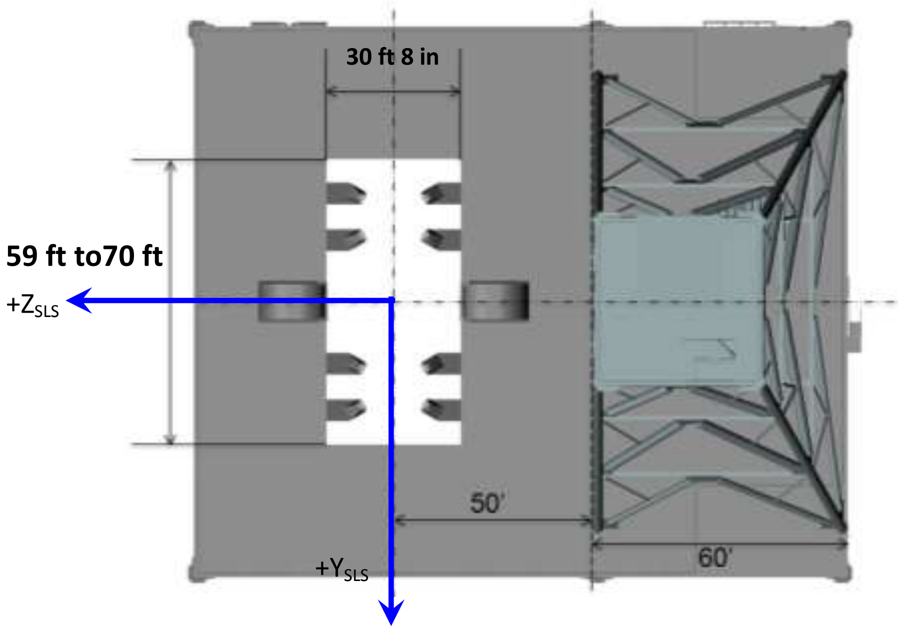

Figure 3 – NASA Notional Top-view of Ground System ML
Looking Down on Mobile Launch Deck ("Zero" Deck Level at X_{SLS}=4867 in)

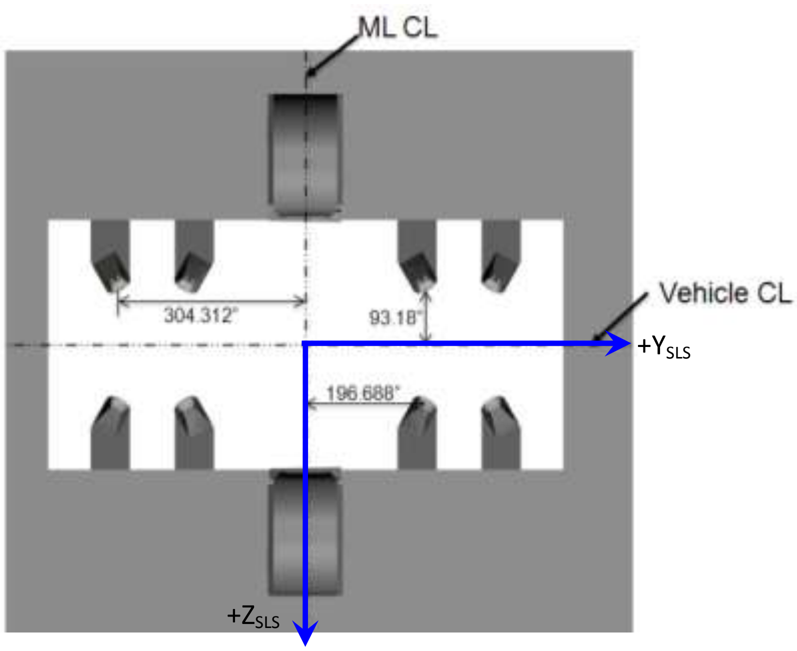

Figure 4 –Advanced Booster to ML Mechanical Lift-off Interface
Detail of Lift-off Post Locations

4.4 Vehicle Load Path

The Advanced Boosters are an integral part of the vehicle structure and will support the total (gross) vehicle mass during assembly, roll out, flight preparation (tanking), core and booster ignition and lift-off, and ascent to booster separation.

The CS is being designed for structural load (thrust takeout) of the booster to be carried at the inter-tank between the liquid hydrogen and liquid oxygen tanks, similar to the Space Shuttle vehicle architecture.

4.5 Advanced Booster Maximum Height

The maximum total height of any Advanced Booster or sub-element must be less than 235 feet to accommodate vehicle stacking and integration in the Vehicle Assembly Building (VAB) at KSC. The constraint comes from lift operations within the VAB. A description of any necessary configuration modifications to the VAB and associated cost estimates to accommodate the Offeror's Advanced Boosters shall be included.

4.6 Vehicle Maximum Width

The total width of the launch vehicle with the proposed Advanced Booster must be less than 67.5 feet (810 inches) to accommodate transport through the VAB doors. A description of any necessary configuration modifications to the VAB doors and associated cost estimates to accommodate the Offeror's Advanced Boosters shall be included.

4.7 Vehicle Dynamic Pressure

The nominal maximum dynamic pressure on the launch vehicle is 800 psf (pounds-force per square foot). The goal is to reduce the maximum dynamic pressure on the vehicle while maintaining performance.

4.8 Vehicle Acceleration

The nominal maximum acceleration on the launch vehicle during propulsive flight is 4.0 g acceleration. The goal is to reduce the maximum acceleration on the vehicle while maintaining performance.